Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–2003/37 September 2003

Survivability, Structures, and Materials Directorate

Technical Report

SIDER Testing of Royal Navy Vessel P292 HMS *Trumpeter*

by

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NSWCCD-65-TR–2003/37 SIDER Testing of Royal Navy Vessel P292 HMS *Trumpeter*

DEPARTMENT OF THE NAVY

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SUBJ: STRUCTURAL IRREGULARITY AND DAMAGE EVALUATION ROUTINE (SIDER) INSPECTION OF SHIP STRUCTURES

Ref: (a) Composite High-Speed Vehicle Task for FY03, Program Element 0603236N

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1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to conduct SIDER inspections of various ship hulls and components. This effort is in support of The Technical Cooperation Program (TTCP), composite panel TP-7, Operating Assignment 026, on the durability assessment of composites in the service environment. This is part of KTA-10, composite performance and long-term durability under dynamic, thermal and shock loading. Enclosure (1) presents the results of a single SIDER inspection of HMS *Trumpeter* (P292) to determine areas of structural differences in its forecastle deck.

2. Comments or questions may be referred to Dr. Roger M. Crane, Code 6553; telephone (301) 227-5126; e-mail, CraneRM@nswccd.navy.mil.

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Subj: STRUCTURAL IRREGULARITY AND DAMAGE EVALUATION ROUTINE (SIDER) INSPECTION OF SHIP STRUCTURES

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Enclosure (1)

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14. ABSTRACT
This report documents work performed by the Naval Surface Warfare Center, Carderock Division in support of The Technical Cooperation Program (TTCP), composite panel TP-7, Operating Assignment 026, on the durability assessment of composites in the service environment. This is part of KTA-10, composite performance and long-term durability under dynamic, thermal and shock loading. This report presents the results of a single Structural Irregularity and Damage Evaluation Routine (SIDER) inspection of the forecastle of HMS Trumpeter, pennant number P292. The forecastle consists of a balsa or plywood core with glass composite facesheets and a top layer of nonskid. The SIDER inspection identified several regions that had changes in structural stiffness. Several of these indications corresponded to structural features in the hull such as deck prisms, vents, and areas where bulkheads terminated. In addition, there was an indication identified where the nonskid material was debonded from the deck. The SIDER inspection failed to identify many nonstructural irregularities since the ship was nearing completion of its refurbishment.

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Administrative Information

The work described in this report was performed by the Structures and Composites Department (Code 65) of the Survivability, Structures and Materials Directorate at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The work was funded by the Chief of Naval Research (ONR 334) as part of the Composite High-Speed Vehicle Task for FY03, Program Element 0603236N.

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Background and Introduction

This report presents the results of a single Structural Irregularity and Damage Evaluation Routine (SIDER) inspection of the forecastle of HMS *Trumpeter*, pennant number P292. HMS *Trumpeter* is a Royal Navy *Archer*-Class fast patrol craft that was, until recently, in service off Gibraltar. The class has a displacement of 88,000 lbs (40 tonnes), is 65-feet 6-inches (twenty meters) long and has a breadth of 19-feet (5.8 meters). The craft have a complement of ten and are unarmed, except in wartime when they are fitted with a 20mm close-range gun. Their maximum speed is 25 knots, being propelled by twin Rolls Royce Eagle Engines - the same type used by the British Army's Chieftain tank.

In early November 2002, The Technical Cooperation Program (TTCP), Composite Panel, TP-7 had their annual meeting at the United States Naval Academy. One of the study assignments presented was Study Assignment 29 on the durability assessment of composites in the service environment. This is part of the KTA-10, Composite Performance and Long-Term Durability under Dynamic, Thermal and Shock Loading. The presentation described the SIDER that is currently being developed at the United States Naval Academy and NSWC, Carderock Division by Drs. Colin Ratcliffe and Roger Crane, respectively.

There was significant interest in this technology and the ability of the SIDER to locate areas of structural differences in complex composite structures. The interest by the member countries was significant enough that the study assignment was elevated to an operating assignment. In this, the member nations work together in the development and transfer of the technology for the mutual benefit of the military of each nation.

In late November 2002, Dr. Paul Curtis, the United Kingdom (UK) National Leader, contacted Dr. Crane and expressed interest by Alan Groves from the UK Ministry of Defence (MoD) at Abbeywood (Bristol) to use SIDER to inspect a GRP hull and sandwich decking on an *Archer*-Class vessel. There have been issues of bonding of the deck to the hull on some ships in this class. It was requested that Drs. Ratcliffe and Crane contact Alan Daniel to discuss the possibility of going to the UK and inspecting the vessels with SIDER.

After several conference calls between the U.S. representatives and representatives of the MoD, it was decided that the SIDER technique may have the capability of locating damage in the *Archer*-Class decks, as well as other composite ship components. A mutually agreeable date and length of stay were determined. The MoD requested that several ship structures be inspected at two shipyards. On the first ship, located at Camper & Nicholsons Yachting Ltd, Mumby Road, Gosport, Hampshire, the forecastle of HMS *Trumpeter*, an *Archer*-Class ship, was to be inspected for any structural irregularity. This report details the results of the testing of HMS *Trumpeter's* forecastle. Figure 1 shows HMS *Raider* (P275), sister ship to HMS *Trumpeter*. Figure 2 shows a general view of HMS *Trumpeter* during testing in the facilities at Camper &

Nicholsons, approximately located at 50° 47.74' N 001° 07.10' W. Testing took place on July 14-15, 2003.

SIDER is the Structural Irregularity and Damage Evaluation Routine. The procedure looks at either the entire structure, or large parts of a structure, and identifies locations where there is variability in structural stiffness. These areas either are due to the design stiffness variability of the structure itself, or are manufacturing defects or in-service damage. After a preliminary SIDER, a follow-up SIDER can be used to show the change that has taken place over time. This change is attributable to damage occurring between the two examinations. For this particular project, HMS *Trumpeter* was subjected to a single SIDER, and therefore it was anticipated that only intentional structural variations would be found. Significant damage was not anticipated since the vessel was at a late stage of refurbishment.

Figure 1. HMS *Raider* (P275), an Archer-Class Vessel

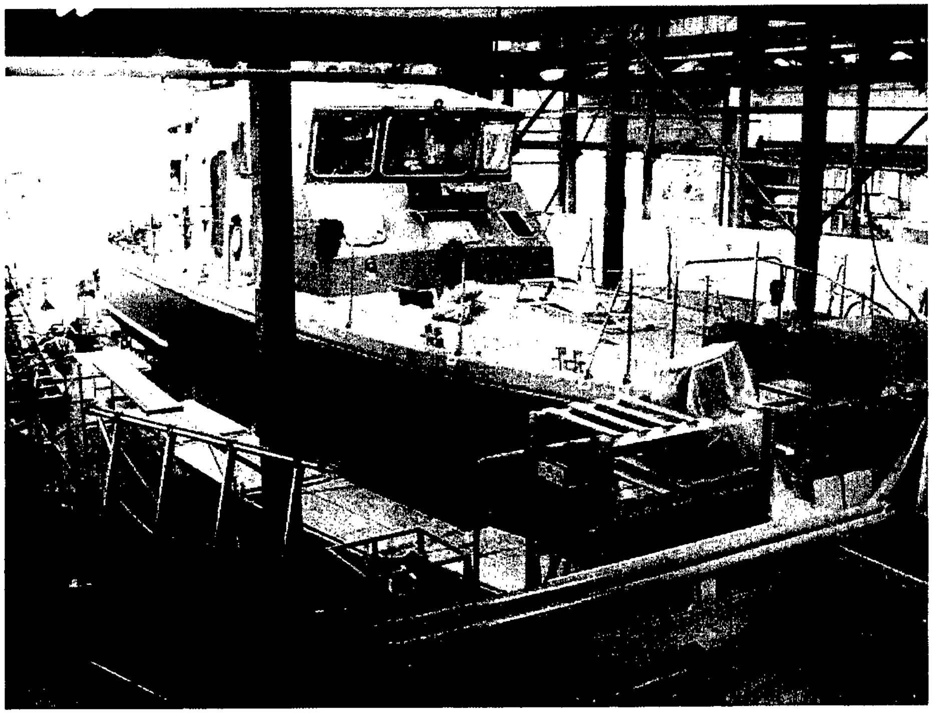

Figure 2. General View of HMS *Trumpeter* (P292) During Testing

Grid

In order to conduct a SIDER analysis, the structure needs to be marked with a mesh of test points. For the best results, the mesh should be uniform. However some irregularity is acceptable. For HMS *Trumpeter*, it was decided to use a basic mesh size of one foot in both the fore-aft and port-starboard directions. To comply with the narrowing nature of the foredeck, the mesh near the forward end was made smaller in the port-starboard direction, but was maintained at one foot in the fore-aft direction. Where points on the regular pattern were coincident with deck features, such as deck prisms, hatches, and so forth, the effected points were moved. The mesh was placed on the structure with white chalk.

Figure 3 shows the test grid with grid point numbering. This grid is repeated in Figure 4, which shows a photograph of the forecastle with the mesh digitally overlayed in black crosses. The locations of the crosses are not exact, but are indicative of the test positions. The mismatch is due to the foreshortening in the photograph, as well as the vertical curvature of the foredeck, which is not modeled in the SIDER test grid.

As shown in the figures, the global origin for measurements was the amidships point, coincident with where the wheelhouse met the surface of the foredeck. The X-direction was forward, the Y-direction was to port, and the Z-direction was up. The slight curvature of the deck was ignored, with all test points being given a Z-value of zero.

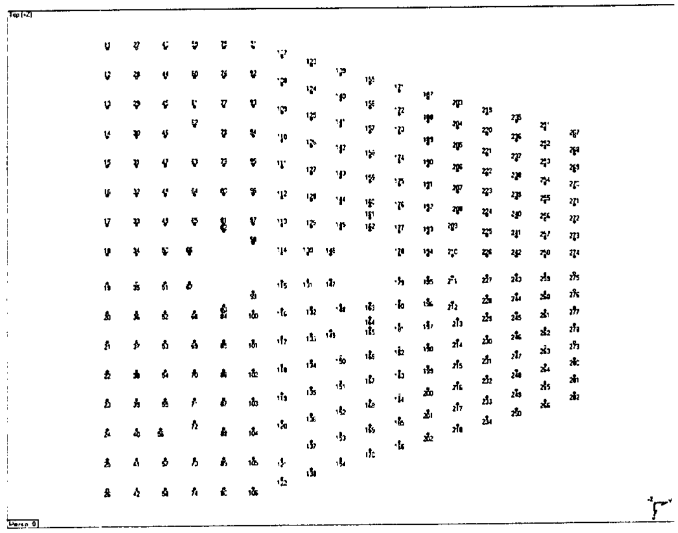

Figure 3. Test Grid for HMS *Trumpeter*

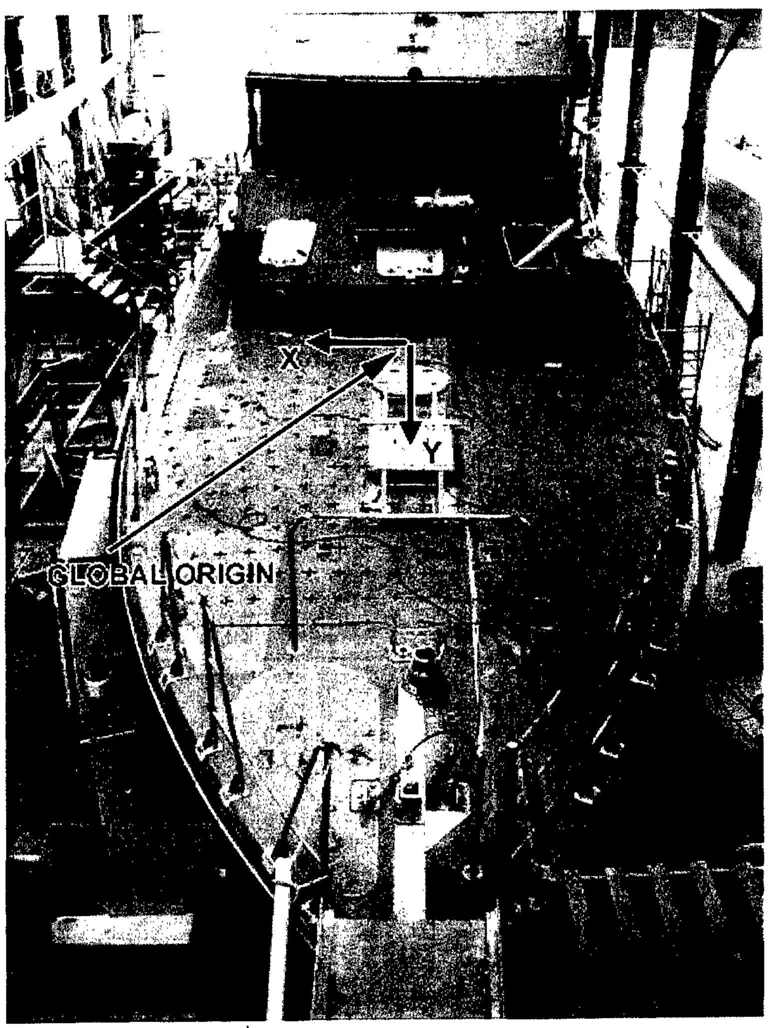

Figure 4. SIDER Test Grid, Origin and Axes Overlayed on the Foredeck

Accelerometer Locations

Most SIDER tests use four accelerometers, arranged on a close-to symmetric pattern. The symmetry is deliberately broken so that the accelerometer locations are partly randomized. For this study it was decided to use six accelerometers. This is because there was a significant stiffener running down the centerline of the foredeck, and it was of concern that excitation on one side of the centerline might not have been detected on the other. By using six accelerometers, it was ensured that there were at least four accelerometers "looking" at each part of the test surface. During the testing, these concerns were unfounded since all six accelerometers responded to excitation throughout the structure. As described later, the SIDER used the data from all six accelerometers. All accelerometers had a nominal sensitivity of 100 mV/g.

The locations of the accelerometers are shown in Table 1. They can also be seen in Figure 5. The absolute location of the transducers is estimated to have an accuracy of ±1.0".

Accelerometer mounting bases were bonded with cyanoacrylate superglue to the cork nonskid surface, which covered the foredeck. The accelerometers were then mounted by stud to the mounting bases.

Table 1. Location of the Accelerometers

Accelerometer	Analyzer Channel	X	Y	Z
A	2	-5'1"	2'9"	0"
B	3	0'0"	2'3"	0"
C	4	5'0"	4'9"	4'9"
D	5	-3'0"	11'9"	0"
E	6	-0'8"	13'9"	0"
F	7	5'6"	10'9"	0"

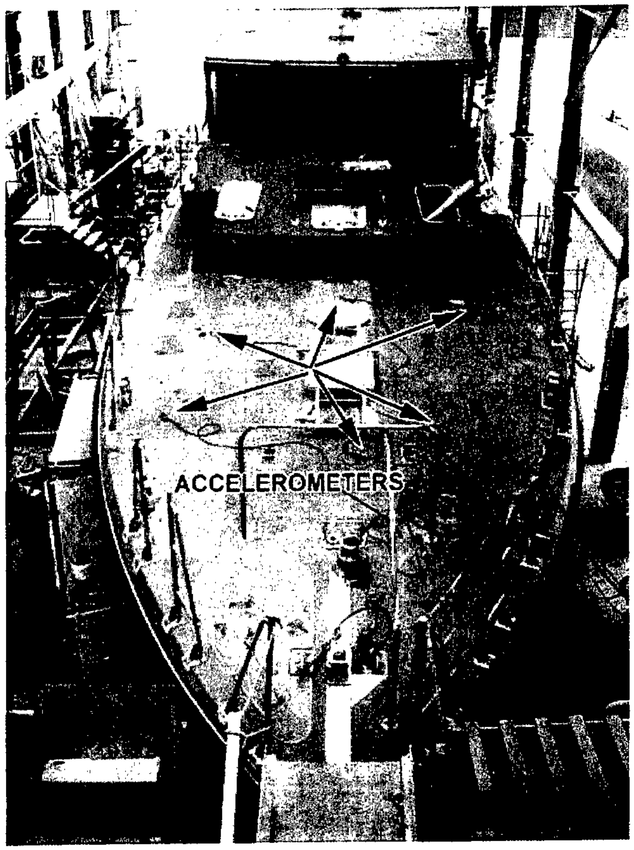

Figure 5. Accelerometer Positions Are at the Head of Each Arrow

Data Acquisition and Quality

Excitation was with the modally tuned midsize sledgehammer with the black tip. This is the hardest tip, and is typically used to ensure input energy across a high frequency range. For this particular application the cork nonskid surface offered a "soft" surface, and therefore the hardest tip was needed to increase the hammer/surface impedance. The impact excitation provided a sufficiently high level of energy up to about 400 Hz. This was, though, adequate for a SIDER analysis.

The data acquisition frequency range was 0-1000 Hz, with a resolution of 0.625 Hz. The response exponential window was optimized at 0.3 seconds. Data for each impact point were spectrally averaged for two hits. On site, the data quality was primarily assessed by observation of the individual coherence functions. When the coherence was atypically poor, the measurement was repeated until either the coherence improved, or it was assessed that the low coherence was a structural issue rather than a test issue.

After the fact, the data quality is assessed by the average coherence. Figure 6 shows the average coherence for each of the accelerometers. In keeping with our standard procedures, the

average coherence is shown separately for each transducer. In this way, instrumentation or local structural problems can sometimes be identified. Note that the coherence axis for each graph is expanded, and only shows the range 80-100%. We would normally consider a high quality data set to have an average coherence in excess of 95%, and preferably more than 98%. We have very high quality data from about 15 to 450 Hz.

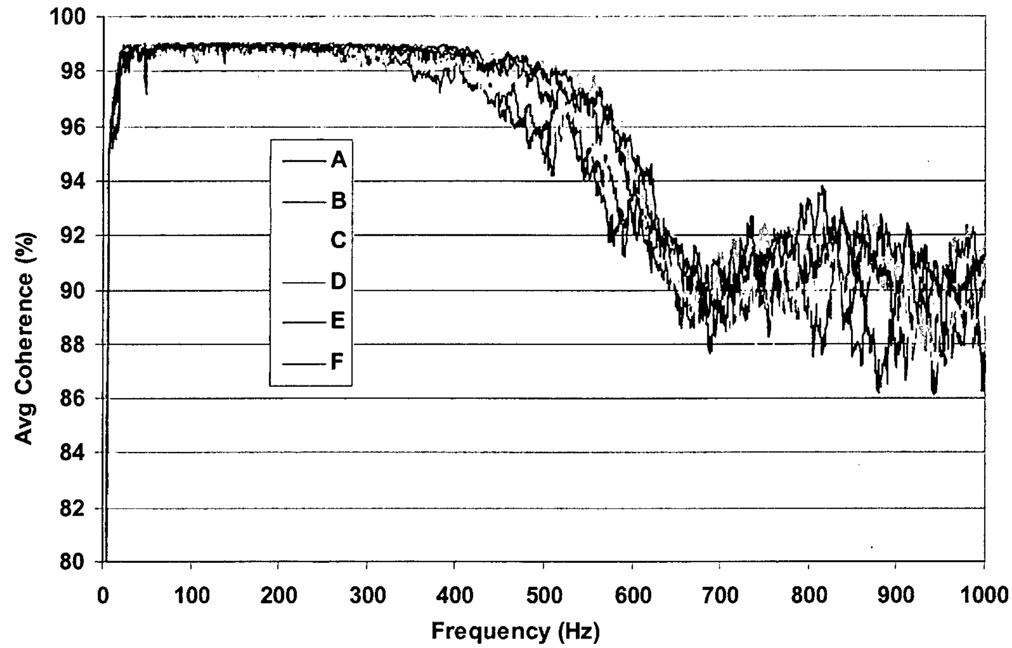

Figure 6. Average Coherence

The conclusion drawn is that all the accelerometers recorded data of a high quality, although, as is normally expected, the data at the highest frequencies have reduced quality. This is because the hammer impact did not put sufficient energy into the structure at these high frequencies to get the response signals sufficiently out of the noise threshold.

Sider Test Results

Based on the coherence data, the SIDER analysis was conducted from 50 to 450 Hz, being a frequency range where the average coherence is above about 98%.

Figure 7 and Figure 8 show the SIDER contour plots. On these plots the small crosses show the test grid and the axes legends show the distance in feet from the global origin. The SIDER is a directional test. Thus there are two results, one for the fore/aft analysis and one for the port/starboard analysis. Each result is shown as a contour plot, and separately overlayed on a photograph of the foredeck. Note that the contour plots can be used to accurately locate features, whereas the foreshortening of the photographs means that features can be shown up to a foot or more from their actual position on the photographs.

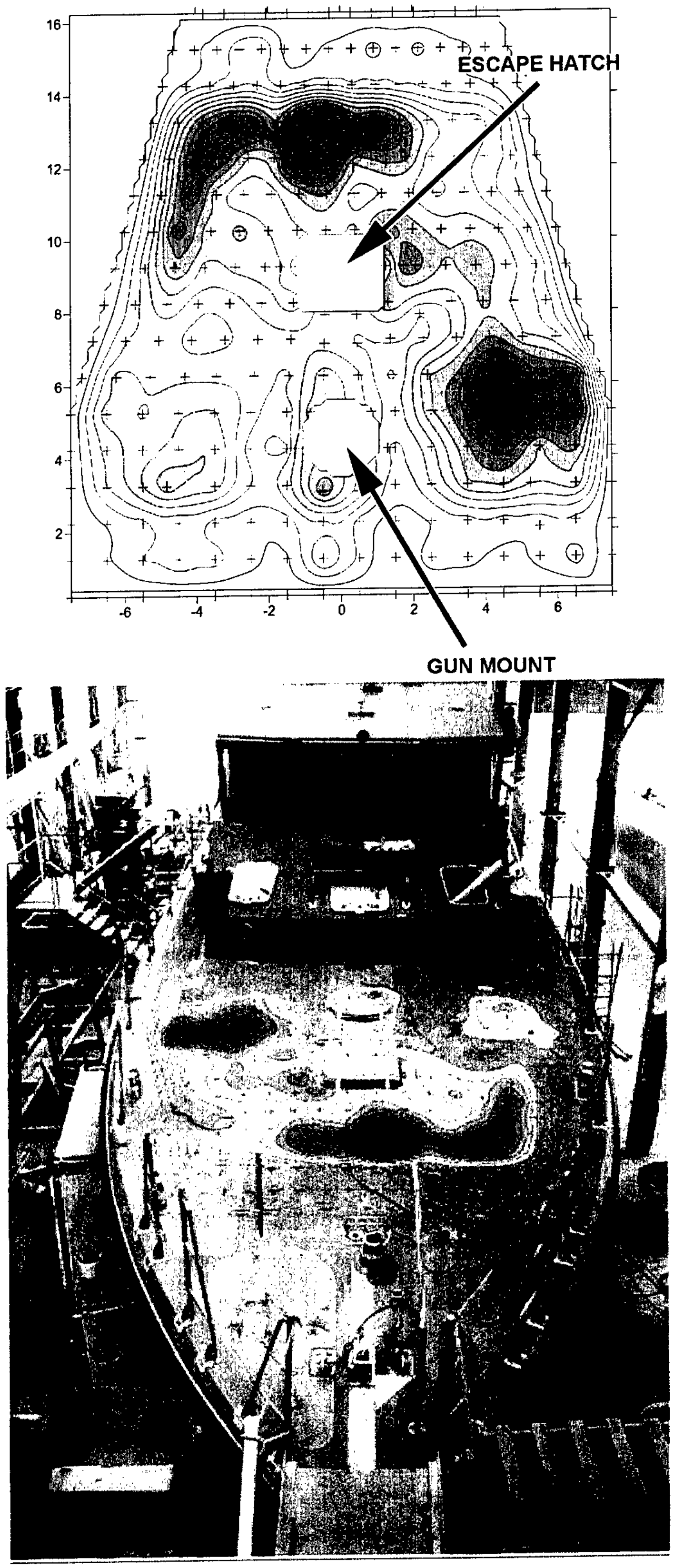

Figure 7. SIDER Fore-Aft Analysis

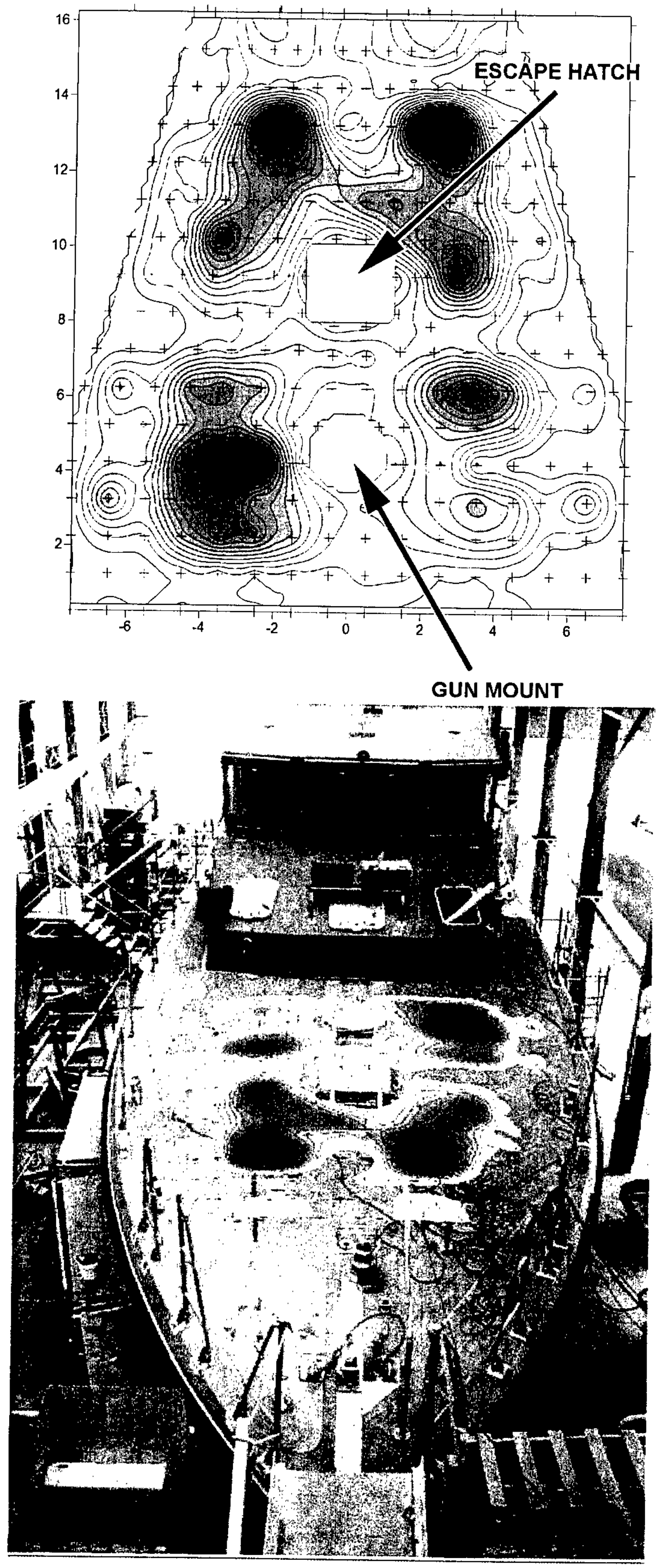

Figure 8. SIDER Port/Starboard Analysis

Discussion of SIDER Results

SIDER is a directional test, and the results can best be interpreted with this in mind. First, the fore-aft analysis will identify regions where the fore-aft stiffness changes. This can be due to several factors, including deliberate design changes (for example, stiffeners running in the port-starboard direction), manufacturing defects or in-service caused damage. It is difficult to use a single SIDER to discriminate between the different causes. However, before/after testing will identify changes happening during the time interval between tests.

Figure 9 repeats Figure 7, but with two features highlighted. Feature 1 is coincident with a structural bulkhead that runs from the starboard side to the gun mount. The bulkhead does not continue to the port side. SIDER has located the stiffness change caused by this bulkhead.

Feature 2 has a maximum at the marked position, but it also extends along a port-starboard line. Just forward of this feature is a significant structural bulkhead that is almost coincident with the forward edge of the test mesh. SIDER has located the stiffness change (reduction) caused by the transition from the stiff area to the main foredeck.

Figure 10 repeats Figure 8, but with several features highlighted. Symmetry can be a powerful assistant in the interpretation of single SIDER results. For example, features marked "3" show symmetry. These features are coincident with deck penetrations (deck prisms). Features 4 and 5 appear to be almost symmetric, but they are not quite symmetric. Feature 4 maps to a deck prism that only exists on the port side. Feature 5 maps to a deck vent that is only on the starboard side.

Feature 6 is a major non-symmetric feature. This feature maps exactly to the lack of bulkhead mentioned in the fore-aft analysis (feature 1). Feature 1 is also coincident with a section where the nonskid surface was not bonded to the substrate, as shown in Figure 11. It is surprising to the authors that SIDER was able to locate this type of problem. The technique typically identifies regions where there are stiffness variations. The reduction in stiffness that the debonded nonskid would result in is assumed to be less than the sensitivity of the detection technique. Physical manipulation of the area, however, did reveal the soft spot that corresponded to the debonded region.

Conclusions

The SIDER technique was used to inspect the forecastle of HMS *Trumpeter*, an *Archer*-Class vessel. The forecastle consists of a balsa or plywood core with glass composite facesheets and a top layer of nonskid. The SIDER inspection identified several regions that had changes in structural stiffness. Several of these indications corresponded to structural features in the hull such as deck prisms, vents, and areas where bulkheads terminated. In addition, there was an indication identified where the nonskid material was debonded from the deck. It is not surprising

that the SIDER inspection failed to identify many nonstructural irregularities since the ship was nearing completion of its refurbishment.

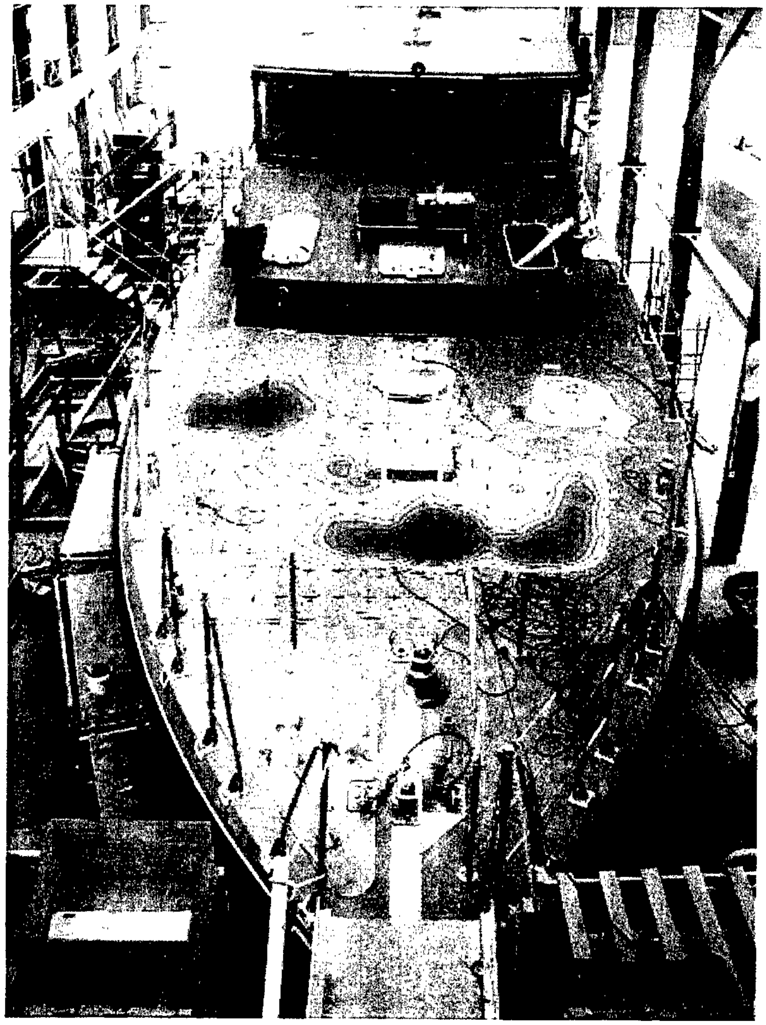

Figure 9. Fore-Aft Analysis with Identified Features

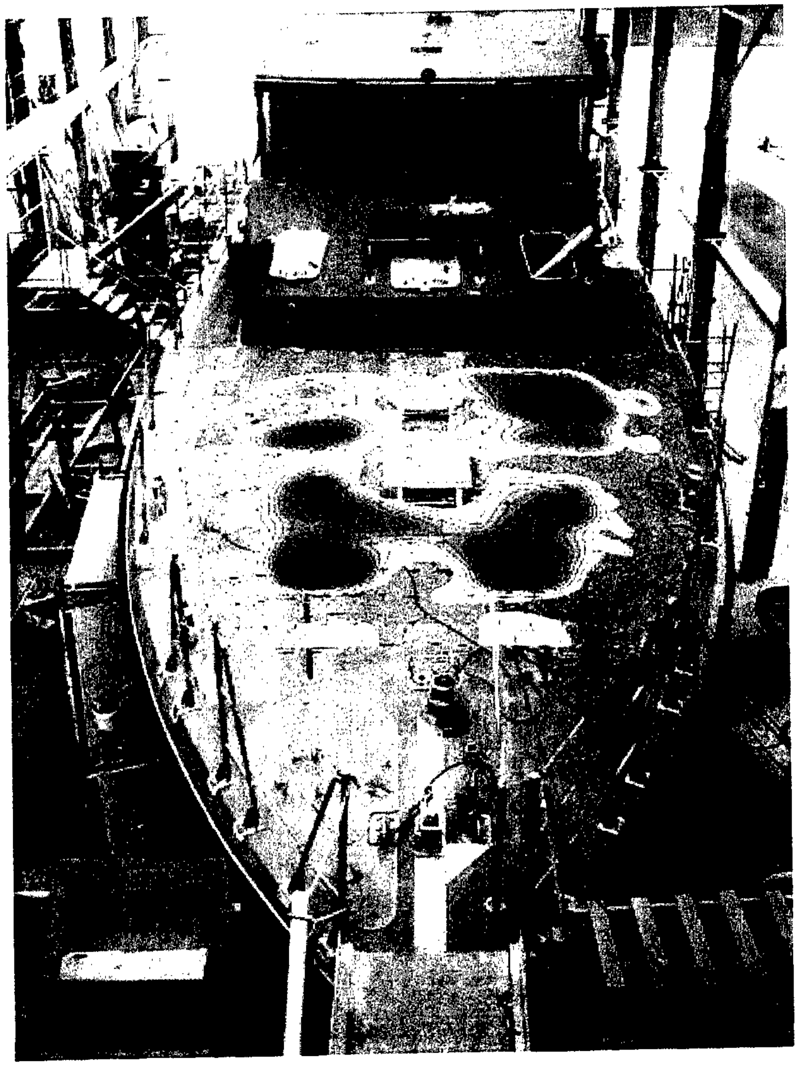

Figure 10. Port-Starboard Analysis with Identified Features

Figure 11. Damage to Nonskid Surface